

Semileptonic $B^- \rightarrow p\bar{p}\ell^-\bar{\nu}_\ell$ decays

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(Dated: October 14, 2011)

Abstract

We study the four-body exclusive semileptonic baryonic \bar{B} decays of $B^- \rightarrow p\bar{p}\ell^-\bar{\nu}_\ell$ ($\ell = e, \mu, \tau$) in the standard model. We find that their decay branching ratios are about $(1.0, 1.0, 0.5) \times 10^{-4}$, respectively. In particular, the electron mode is close to the corresponding CLEO's upper limit of 5.2×10^{-3} , while all results are about one or two orders of magnitude larger than the previous estimated values for the inclusive modes of $\bar{B} \rightarrow \mathbf{B}\bar{\mathbf{B}}'\ell\bar{\nu}$. Clearly, both B-factories of Belle and BaBar should be able to observe these exclusive four-body modes.

I. INTRODUCTION

In the semileptonic $\bar{B} \rightarrow M \ell \bar{\nu}_\ell$ decay with a meson M and a charged lepton ℓ , the $\ell \bar{\nu}_\ell$ pair involves no direct QCD interaction so that the theoretical description of the amplitude can be reduced to a simple form with the $\bar{B} \rightarrow M$ transition. For example, the rate for $\bar{B}^0 \rightarrow \pi^+ e^- \bar{\nu}_e$ is proportional to $|V_{ub} f_+(q^2)|^2$, where the form factor $f_+(q^2)$ for the $\bar{B}^0 \rightarrow \pi^+$ transition depends on the momentum transfer squared, q^2 . This benefits the precision measurement of $|V_{ub}|$, where $|V_{ub}|$ is one of the least known Cabibbo-Kobayashi-Maskawa (CKM) matrix elements [1, 2] in the Standard Model (SM). As long as we choose a point $q^2 = q_i^2$ in the decay spectrum, the corresponding data point with other parameters can be fixed to extract the value of $|V_{ub}|$. However, $f_+(q^2)$ relies on the calculations in the QCD models, such as quark models [3], lattice QCD [4], and Light Cone Sum Rules [5]. Starting with q_i^2 and $|V_{ub}|$, one is allowed to inversely extract the q^2 dependence of $f_+(q^2)$ in different q^2 intervals from the measured data [6–10]. The extraction compared with various theoretical models hence improves the knowledge of $f_+(q^2)$. Moreover, such extraction also provides crosschecks for the $\bar{B} \rightarrow \rho$ and $\bar{B} \rightarrow \eta^{(\prime)}$ transition form factors [8–10]. In particular, the size of the gluonic singlet contribution [11–13] to the $\bar{B} \rightarrow \eta'$ transition to explain the unexpectedly large two-body hadronic $\bar{B} \rightarrow K \eta'$ decay rate has been constrained by measuring $\bar{B} \rightarrow \eta^{(\prime)} \ell \bar{\nu}$ decays [8–10]. Similar to the mesonic cases, it should be interesting to extend the study to baryonic decay modes, such as $\bar{B} \rightarrow \mathbf{B} \bar{\mathbf{B}}' \ell \bar{\nu}$ with $\mathbf{B} \bar{\mathbf{B}}'$ being a baryon pair, to investigate the $\bar{B} \rightarrow \mathbf{B} \bar{\mathbf{B}}'$ transition form factors, which have been used as theoretical inputs in the three-body $\bar{B} \rightarrow p \bar{p} M$ decays.

The factorizable amplitudes for the three-body baryonic $\bar{B} \rightarrow \mathbf{B} \bar{\mathbf{B}}' M$ decays are normally classified into current and transition parts, given by

$$\begin{aligned}\mathcal{A}_C &\propto \langle \mathbf{B} \bar{\mathbf{B}}' | (\bar{q}_1 q_2) | 0 \rangle \langle M | (\bar{q}_3 b) | \bar{B} \rangle, \\ \mathcal{A}_T &\propto \langle M | (\bar{q}_1 q_2) | 0 \rangle \langle \mathbf{B} \bar{\mathbf{B}}' | (\bar{q}_3 b) | \bar{B} \rangle,\end{aligned}\tag{1}$$

respectively, where $(\bar{q}_1 q_2)$ and $(\bar{q}_3 b)$ stand for the weak currents. The matrix elements of $0 \rightarrow \mathbf{B} \bar{\mathbf{B}}'$ in \mathcal{A}_C are presented as the timelike baryonic form factors, for which the theoretical calculations are available, such as the approach of the pQCD counting rules [14–16]. Consequently, the observed branching ratios for $\bar{B}^0 \rightarrow n \bar{p} D^{*+}$ [17], $B^- \rightarrow \Lambda \bar{p} \pi^-$ [18–21] and $\bar{B} \rightarrow \Lambda \bar{\Lambda} \bar{K}^{(*)}$ [22, 23] can be explained due to the \mathcal{A}_C -like amplitudes [24–32]. On the other

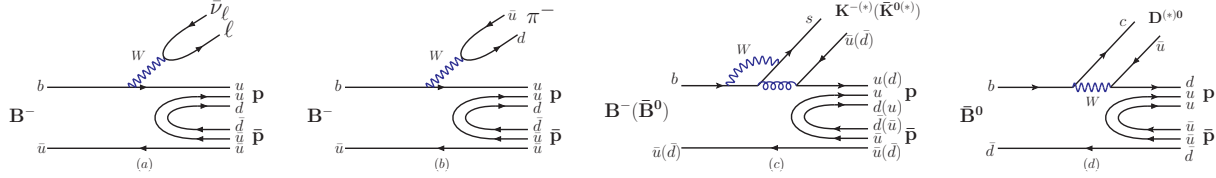


FIG. 1. Baryonic \bar{B} decays with the $\bar{B} \rightarrow p\bar{p}$ transition, where (a) $B^- \rightarrow p\bar{p}\ell\bar{\nu}_\ell$, (b) $B^- \rightarrow p\bar{p}\pi^-$, (c) $\bar{B} \rightarrow p\bar{p}\bar{K}^{(*)}$, and (d) $\bar{B}^0 \rightarrow p\bar{p}D^{(*)0}$.

hand, the measured decays of $\bar{B} \rightarrow p\bar{p}\bar{K}^{(*)}$, $B^- \rightarrow p\bar{p}\pi^-$ [20, 33–37], and $\bar{B}^0 \rightarrow p\bar{p}D^{(*)0}$ [38, 39], shown in Fig. 1, are considered to have \mathcal{A}_T as their amplitudes [25, 27, 31, 32, 40–42]. To explain the data, the transition matrix elements of $\bar{B} \rightarrow \mathbf{B}\bar{\mathbf{B}}'$ are parameterized in terms of various form factors [27, 31, 32, 40–42]. As seen in Fig. 1, the decay of $B^- \rightarrow p\bar{p}\ell\bar{\nu}_\ell$ is also a \mathcal{A}_T type as $\bar{B} \rightarrow p\bar{p}M$. It is clear that the observation of $B^- \rightarrow p\bar{p}\ell\bar{\nu}_\ell$ shall directly determine the transition form factors, which have been widely used to explain the $\bar{B} \rightarrow p\bar{p}M$ data as theoretical inputs. In analogy with the timelike baryonic form factors, similar momentum dependences of the transition form factors may be chosen, which can be justified by investigating the shape of the invariant mass spectrum for the $B^- \rightarrow p\bar{p}\ell^-\bar{\nu}_\ell$ decay. Moreover, we expect that the measurements of the angular distributions in $B^- \rightarrow p\bar{p}e^-\bar{\nu}_e$ will provide some information to understand the unexpectedly large angular distribution asymmetries of $\mathcal{A}_\theta(B^- \rightarrow p\bar{p}K^-) = 0.45 \simeq -\mathcal{A}_\theta(B^- \rightarrow p\bar{p}\pi^-)$ [35].

At present, the CLEO Collaboration has given an experimental upper limit: [43]

$$\mathcal{B}(B^- \rightarrow p\bar{p}e^-\bar{\nu}_e) < 5.2 \times 10^{-3} \text{ (90\% C.L.)}, \quad (2)$$

while the theoretical estimation has only been done for the inclusive $\bar{B} \rightarrow \mathbf{B}\bar{\mathbf{B}}'\ell\bar{\nu}$ decays with charmless dibaryons, given by [44]

$$\mathcal{B}(\bar{B} \rightarrow \mathbf{B}\bar{\mathbf{B}}'\ell\bar{\nu}) \simeq 10^{-5} - 10^{-6}. \quad (3)$$

In this paper, we concentrate on the exclusive four-body semileptonic baryonic decay of $B^- \rightarrow p\bar{p}\ell\bar{\nu}_\ell$ ($\ell = e, \mu$, or τ). In particular, we will study its decay branching ratio in the SM.

The paper is organized as follows. In Sec. II, we provide the formalism, in which we show the decay amplitude and rate of $B^- \rightarrow p\bar{p}\ell\bar{\nu}_\ell$ along with the definitions of the transition form factors of $\bar{B} \rightarrow \mathbf{B}\bar{\mathbf{B}}'$. We give our numerical results and discussions in Sec. III. In Sec. IV, we present the conclusions.

II. FORMALISM

In terms of the effective Hamiltonian, given by

$$\mathcal{H}(b \rightarrow u \ell \bar{\nu}) = \frac{G_F V_{ub}}{\sqrt{2}} \bar{u} \gamma_\mu (1 - \gamma_5) b \bar{\ell} \gamma^\mu (1 - \gamma_5) \nu, \quad (4)$$

for the $b \rightarrow u$ transition with the W boson emission to $\ell \bar{\nu}$ at the quark level, we easily factorize the amplitude for the $B^- \rightarrow p \bar{p} \ell \bar{\nu}_\ell$ decay to be

$$\mathcal{A}(B^- \rightarrow p \bar{p} \ell \bar{\nu}_\ell) = \frac{G_F V_{ub}}{\sqrt{2}} \langle p \bar{p} | \bar{u} \gamma_\mu (1 - \gamma_5) b | B^- \rangle \bar{\ell} \gamma^\mu (1 - \gamma_5) \nu_\ell, \quad (5)$$

where we have parameterized the amplitude in terms of the transition matrix element of $\bar{B} \rightarrow p \bar{p}$. With Lorentz invariance, the most general forms of the $\bar{B} \rightarrow \mathbf{B} \bar{\mathbf{B}}'$ transition form factors can be written as [31]

$$\begin{aligned} \langle \mathbf{B} \bar{\mathbf{B}}' | \bar{q}' \gamma_\mu b | \bar{B} \rangle &= i \bar{u}(p_{\mathbf{B}}) [g_1 \gamma_\mu + g_2 i \sigma_{\mu\nu} p^\nu + g_3 p_\mu + g_4 (p_{\bar{\mathbf{B}}'} + p_{\mathbf{B}})_\mu + g_5 (p_{\bar{\mathbf{B}}'} - p_{\mathbf{B}})_\mu] \gamma_5 v(p_{\bar{\mathbf{B}}'}), \\ \langle \mathbf{B} \bar{\mathbf{B}}' | \bar{q}' \gamma_\mu \gamma_5 b | \bar{B} \rangle &= i \bar{u}(p_{\mathbf{B}}) [f_1 \gamma_\mu + f_2 i \sigma_{\mu\nu} p^\nu + f_3 p_\mu + f_4 (p_{\bar{\mathbf{B}}'} + p_{\mathbf{B}})_\mu + f_5 (p_{\bar{\mathbf{B}}'} - p_{\mathbf{B}})_\mu] v(p_{\bar{\mathbf{B}}'}), \end{aligned} \quad (6)$$

with $p = p_B - p_{\mathbf{B}} - p_{\bar{\mathbf{B}}'}$ for the vector and axial-vector quark currents, respectively. For the momentum dependences of f_i and g_i , we can rely on the results in the $\bar{B} \rightarrow p \bar{p} M$ decays as they share the same $\bar{B} \rightarrow \mathbf{B} \bar{\mathbf{B}}'$ transition form factors. Since the $p \bar{p}$ invariant mass distributions for $\bar{B} \rightarrow p \bar{p} M$ have been observed to peak near the threshold area and flatten out at the large energy region, inspired by the pQCD counting rules [14–16, 27], we simply take the form factors as [40]

$$f_i = \frac{D_{f_i}}{t^n}, \quad g_i = \frac{D_{g_i}}{t^n}, \quad (7)$$

with $n = 3$ and $t \equiv (p_p + p_{\bar{p}})^2 \equiv m_{p\bar{p}}^2$ where D_{f_i} and D_{g_i} are constants determined by the $\bar{B} \rightarrow p \bar{p} M$ data. Note that the number of $n = 3$ is for three hard gluons as the propagators to form a baryon pair in the approach of the pQCD counting rules, where two of them attach to valence quarks in $p \bar{p}$, while the third one kicks and speeds up the spectator quark in \bar{B} . In terms of Eqs. (5), (6), and (7), the amplitude squared $|\bar{\mathcal{A}}|^2$ by summing over all fermion spins becomes available.

We then need the kinematics for the four-body $\bar{B}(p_{\bar{B}}) \rightarrow \mathbf{B}(p_{\mathbf{B}}) \bar{\mathbf{B}}'(p_{\bar{\mathbf{B}}'}) \ell(p_\ell) \bar{\nu}(p_{\bar{\nu}})$ decay to integrate over the phase space. As the formalisms in K_{l4} , D_{l4} , and B_{l4} decays given in Refs. [45–47], we use five kinematic variables, $s \equiv (p_\ell + p_{\bar{\nu}})^2 \equiv m_{\ell\bar{\nu}}^2$, t , $\theta_{\mathbf{B}}$, $\theta_{\mathbf{L}}$, and ϕ to describe the decay. The three angles $\theta_{\mathbf{B}}$, $\theta_{\mathbf{L}}$, and ϕ are depicted in Fig. 2, where the angle

$\theta_{\mathbf{B}(\mathbf{L})}$ is between $\vec{p}_{\mathbf{B}}$ (\vec{p}_{ℓ}) in the $\mathbf{B}\bar{\mathbf{B}}'$ ($\ell\bar{\nu}$) rest frame and the line of flight of the $\mathbf{B}\bar{\mathbf{B}}'$ ($\ell\bar{\nu}$) system in the rest frame of the \bar{B} meson, while the angle ϕ is from the $\mathbf{B}\bar{\mathbf{B}}'$ plane defined by the momenta of the $\mathbf{B}\bar{\mathbf{B}}'$ pair to the $\ell\bar{\nu}$ plane defined by the momenta of the $\ell\bar{\nu}$ pair in the rest frame of \bar{B} . The partial decay width reads

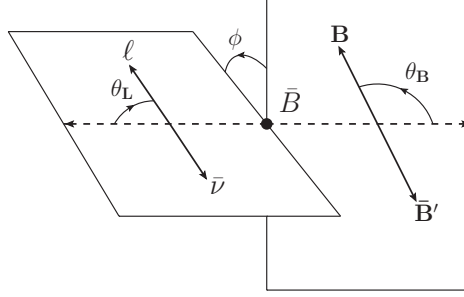


FIG. 2. Three angles of $\theta_{\mathbf{B}}$, $\theta_{\mathbf{L}}$, and ϕ in $\bar{B} \rightarrow \mathbf{B}\bar{\mathbf{B}}'\ell\bar{\nu}$.

$$d\Gamma = \frac{|\bar{\mathcal{A}}|^2}{4(4\pi)^6 m_{\bar{B}}^3} X \beta_{\mathbf{B}} \beta_{\mathbf{L}} ds dt d\cos\theta_{\mathbf{B}} d\cos\theta_{\mathbf{L}} d\phi, \quad (8)$$

where X , $\beta_{\mathbf{B}}$, and $\beta_{\mathbf{L}}$ are given by

$$\begin{aligned} X &= \left[\frac{1}{4}(m_{\bar{B}}^2 - s - t)^2 - st \right]^{1/2}, \\ \beta_{\mathbf{B}} &= \frac{1}{t} \lambda^{1/2}(t, m_{\mathbf{B}}^2, m_{\bar{\mathbf{B}}'}^2), \\ \beta_{\mathbf{L}} &= \frac{1}{s} \lambda^{1/2}(s, m_{\ell}^2, m_{\bar{\nu}}^2), \end{aligned} \quad (9)$$

respectively, with $\lambda(a, b, c) = a^2 + b^2 + c^2 - 2ab - 2bc - 2ca$. The regions for the five variables of the phase space are given by

$$\begin{aligned} (m_{\ell} + m_{\bar{\nu}})^2 &\leq s \leq (m_{\bar{B}} - \sqrt{t})^2, \quad (m_{\mathbf{B}} + m_{\bar{\mathbf{B}}'})^2 \leq t \leq (m_{\bar{B}} - m_{\ell} - m_{\bar{\nu}})^2, \\ 0 &\leq \theta_{\mathbf{L}}, \theta_{\mathbf{B}} \leq \pi, \quad 0 \leq \phi \leq 2\pi. \end{aligned} \quad (10)$$

III. NUMERICAL RESULTS AND DISCUSSIONS

In our numerical analysis, we take $|V_{ub}| = (3.89 \pm 0.44) \times 10^{-3}$ from the PDG [48]. To deal with D_{g_i} and D_{f_i} in Eq. (7), it is helpful to use the approach of the pQCD counting rules again, where with $SU(3)$ flavor and $SU(2)$ spin symmetries the vector and axial-vector currents are incorporated as two chiral currents in the large t limit [27, 31, 40]. Consequently,

D_{g_i} and D_{f_i} from the vector currents are related by another set of constants D_{\parallel} and D_{\perp} from the chiral currents. Explicitly, for the $B^- \rightarrow p\bar{p}$ transition form factors we have [31, 40]

$$D_{g_1} = \frac{5}{3}D_{\parallel} - \frac{1}{3}D_{\perp}, \quad D_{f_1} = \frac{5}{3}D_{\parallel} + \frac{1}{3}D_{\perp}, \quad D_{g_j} = \frac{5}{3}D_{\parallel}^j = -D_{f_j}, \quad (11)$$

with $j = 2, 3, \dots, 5$, where their values are determined by fitting the data of the total branching ratios, invariant mass spectra, and angular distributions measured in the $\bar{B} \rightarrow p\bar{p}M$ decays. To illustrate our results, we adopt the values in Ref. [31]:

$$\begin{aligned} (D_{\parallel}, D_{\perp}) &= (67.7 \pm 16.3, -280.0 \pm 35.9) \text{ GeV}^5, \\ (D_{\parallel}^2, D_{\parallel}^3, D_{\parallel}^4, D_{\parallel}^5) &= \\ &(-187.3 \pm 26.6, -840.1 \pm 132.1, -10.1 \pm 10.8, -157.0 \pm 27.1) \text{ GeV}^4. \end{aligned} \quad (12)$$

Thus, the total branching ratios of $B^- \rightarrow p\bar{p}\ell\bar{\nu}_{\ell}$ are found to be

$$\begin{aligned} \mathcal{B}(B^- \rightarrow p\bar{p}e^-\bar{\nu}_e) &= (1.04 \pm 0.26 \pm 0.12) \times 10^{-4}, \\ \mathcal{B}(B^- \rightarrow p\bar{p}\mu^-\bar{\nu}_{\mu}) &= (1.04 \pm 0.24 \pm 0.12) \times 10^{-4}, \\ \mathcal{B}(B^- \rightarrow p\bar{p}\tau^-\bar{\nu}_{\tau}) &= (0.46 \pm 0.10 \pm 0.05) \times 10^{-4}, \end{aligned} \quad (13)$$

where the two errors in Eq. (13) are from those in Eq. (12) and $|V_{ub}|$, respectively. The invariant mass spectra and angular distributions for $B^- \rightarrow p\bar{p}e^-\bar{\nu}_e$ are shown in Fig. 3. The

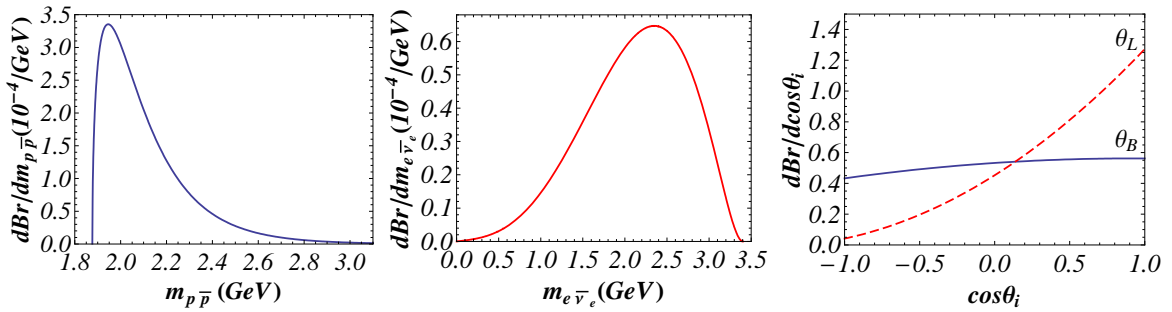


FIG. 3. Invariant mass spectra as functions of the invariant masses $m_{p\bar{p}}$ and $m_{e\bar{\nu}_e}$ and angular distributions as functions of θ_i ($i = B, L$) for $B^- \rightarrow p\bar{p}e^-\bar{\nu}_e$, respectively.

integrated angular distribution asymmetries, defined by

$$\mathcal{A}_{\theta_i} \equiv \frac{\int_0^1 \frac{d\mathcal{B}}{d\cos\theta_i} d\cos\theta_i - \int_{-1}^0 \frac{d\mathcal{B}}{d\cos\theta_i} d\cos\theta_i}{\int_0^1 \frac{d\mathcal{B}}{d\cos\theta_i} d\cos\theta_i + \int_{-1}^0 \frac{d\mathcal{B}}{d\cos\theta_i} d\cos\theta_i}, \quad (i = B, L) \quad (14)$$

are obtained to be

$$\begin{aligned}\mathcal{A}_{\theta_B}(B^- \rightarrow p\bar{p}e^-\bar{\nu}_e) &= 0.06 \pm 0.02, \\ \mathcal{A}_{\theta_L}(B^- \rightarrow p\bar{p}e^-\bar{\nu}_e) &= 0.59 \pm 0.02,\end{aligned}\tag{15}$$

where the errors are from those in Eq. (12).

Since our result on $\mathcal{B}(B^- \rightarrow p\bar{p}e^-\bar{\nu}_e)$ in Eq. (13) is around 1.0×10^{-4} , which is the same order of magnitude as those of the well measured mesonic B decays at Belle and BaBar, such as $\mathcal{B}(\bar{B}^0 \rightarrow \pi^+(\rho^+)\ell^-\bar{\nu}_\ell)$ and $\mathcal{B}(B^- \rightarrow \rho^0\ell^-\bar{\nu}_\ell)$, this four-body mode should be observed at these B-factories [49]. Moreover, as seen from Fig. 3a, the $B^- \rightarrow p\bar{p}e^-\bar{\nu}_e$ decay inherits the same threshold enhancement as those in the three-body baryonic \bar{B} decays, resulting from the adoption of $1/t^3$ for the momentum dependence in the $B^- \rightarrow p\bar{p}$ transition form factors. The spectrum in Fig. 3b reflects the fact that in the helicity structure the amplitude of the $e^-\bar{\nu}_e$ pair is proportional to $(E_e + E_{\bar{\nu}_e})$.

It is interesting to note that our study of $B^- \rightarrow p\bar{p}\ell\bar{\nu}_\ell$ is similar to that of $B^- \rightarrow p\bar{p}K^{*-}$ [40–42]. The terms related to g_2 and f_2 in the $B^- \rightarrow p\bar{p}$ transition form factors give the main contributions to $B^- \rightarrow p\bar{p}\ell\bar{\nu}_\ell$. Since the pair of the left-handed electron and the right-handed anti-neutrino in the helicity structure behaves as one of the polarization vector $\varepsilon_-^\mu(p)$ with $p = p_\ell + p_{\bar{\nu}_\ell}$, leading to $\varepsilon \cdot p = 0$, the contributions from f_3 and g_3 disappear. Those from f_4 and g_4 are effectively small due to the tiny $|D_\parallel^4| \simeq 10 \text{ GeV}^4$. As the branching ratio receives the most contribution near the threshold area, the $g_5(f_5)$ -accompanied term $(p_{\bar{p}} - p_p) = (E_{\bar{p}} - E_p, \vec{p}_{\bar{p}} - \vec{p}_p) \rightarrow (0, \vec{0})$ is suppressed. Moreover, since the terms of g_2 and f_2 contain $\sigma_{\mu\nu}p^\nu$, we have the relation $|D_{g_2(f_2)}p| \simeq 300 |p| \text{ GeV}^5 > |D_{f_1}| \simeq 200 \text{ GeV}^5 \gg |D_{g_1}| \simeq 20 \text{ GeV}^5$, which explains why g_2 and f_2 prevail over other terms in the $B^- \rightarrow p\bar{p}\ell\bar{\nu}_\ell$ decay.

Finally, it is interesting to point out that the angular distribution asymmetries in Eq. (14) in the $B^- \rightarrow p\bar{p}\ell\bar{\nu}_\ell$ decay are sensitive to new physics, such as the currents of $(V + A)$ and $(S \pm P)$ beyond the SM. Note that $\mathcal{A}_{\theta_L} = 0.59$ in Eq. (15) (see also Fig. 3c) is caused by the $\ell^-\bar{\nu}_\ell$ pair of $(V - A)$ in the SM, which forms a polarization vector $\varepsilon_-^\mu(p)$ to couple to the left-handed helicity state of the virtual weak boson W^{*-} . Therefore, a new physics with the $(V + A)$ current, which lets the $\ell\bar{\nu}_\ell$ pair to be another polarization state $\varepsilon_+^\mu(p)$, must result in the deviation of \mathcal{A}_{θ_L} in Eq. (15). Apart from a direct CP violation [41], $B^- \rightarrow p\bar{p}\ell\bar{\nu}_\ell$ can easily create T -odd triple product correlations (TPC's) to test direct T violation effects.

Since the three-momenta of $p\bar{p}$ and those of $\ell\bar{\nu}_\ell$ are not in the same plane, $\vec{p}_\ell \cdot (\vec{p}_p \times \vec{p}_{\bar{p}})$ can be a nonzero TPC observable. Like the case of $\vec{s}_\Lambda \cdot (\vec{p}_\Lambda \times \vec{p}_{\bar{p}})$ in $\bar{B}^0 \rightarrow \Lambda \bar{p} \pi^-$ [50] with \vec{s}_Λ denoting the Λ spin, there are other TPC observables $\vec{s}_\ell \cdot (\vec{p}_p \times \vec{p}_{\bar{p}})$ and $\vec{s}_p \cdot (\vec{p}_p \times \vec{p}_{\bar{p}})$ in $B^- \rightarrow p\bar{p}\ell\bar{\nu}_\ell$. These rich TPC observables are expected to be useful to test new physics in the advantage of \mathcal{B} of order 10^{-4} much larger than the sensitivity of 10^{-7} in the B factories.

IV. CONCLUSIONS

We have examined the four-body semileptonic baryonic \bar{B} decay of $B^- \rightarrow p\bar{p}\ell\bar{\nu}_\ell$ in the SM, which proceeds via $b \rightarrow u\ell\bar{\nu}_\ell$ at the quark level. The transition form factors of $B^- \rightarrow p\bar{p}$, which are well studied in the three-body baryonic $\bar{B} \rightarrow p\bar{p}M$ decays, play the key role in the theoretical calculation. We have found that $\mathcal{B}(B^- \rightarrow p\bar{p}\ell\bar{\nu}_\ell) = (1.04, 1.04, 0.46) \times 10^{-4}$ for $\ell = e, \mu, \tau$, respectively, which are just a little below the CLEO's upper limit of 5.2×10^{-3} for $\mathcal{B}(B^- \rightarrow p\bar{p}e^-\bar{\nu}_e)$ but much larger than the previous estimations of $10^{-5} - 10^{-6}$ for the inclusive modes of $\bar{B} \rightarrow \mathbf{B}\bar{\mathbf{B}}'\ell\bar{\nu}$. It is clear that the four-body decays of $B^- \rightarrow p\bar{p}\ell\bar{\nu}_\ell$, in particular the light charged lepton modes, should be observed by the B-factories of Belle and BaBar as well as future B-factories, such as Super-Belle and LHCb.

ACKNOWLEDGMENTS

The work was supported in part by National Center of Theoretical Science and National Science Council (NSC-98-2112-M-007-008-MY3) of R.O.C.

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